CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-207

SUPERSTITION HILLS, SUPERSTITION MOUNTAIN, AND RELATED FAULTS
Imperial County, California

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INTRODUCTION

The Superstition Hills fault is a northwest to west-northwest trending 23+ km (14.5 mi.) long right-lateral strike-slip fault which has had repeated episodes of historic movement. The recently mapped and named Wienert fault (Sharp and others, 1989) steps right from the southern end of the Superstition-Hills fault, and extends the zone of faulting to more than 27 km (17 mi.). The Superstition Mountain fault is a northwest trending 18+ km (11+ mi.) long right-oblique fault which has not had any documented historic displacement but does exhibit evidence of Holocene activity. These faults, located along the western margin of the Imperial Valley (see Figure 1), are considered to be the southern extension of the San Jacinto fault zone (Tarbet, 1951; Dibblee, 1954; Sharp, 1972). A set of named and unnamed left-lateral strike-slip faults extend north-northeasterly from the Superstition Hills fault where it curves through the Superstition Hills (Plate 1a). Several of these faults, which include the Elmore Desert Ranch (east, main, and west traces), Kane Spring, East Kane Spring and the Lone Tree faults, experienced surface rupture during the November 1987 Elmore Desert Ranch and Superstition Hills earthquakes. The Superstition Hills and Superstition Mountain faults are currently within Alquist-Priolo Special Studies Zones on the Kane Spring, Plaster City NW, Superstition Mtn., Brawley, Brawley NW, and El Centro quadrangles (Hart, 1988).

The purpose of this evaluation is to revise the Special Study Zone for the Superstition Hills fault to include recent rupture in the Seeley quadrangle and the Brawley NW quadrangle. It is also intended to establish zones around several recently active north-northeast trending faults in the Kane Spring quadrangle. The currently established zone for the Superstition Mountain fault is reviewed for revision based on recent studies (Hudnut and Williams, 1987) and new aerial photography.

SUMMARY OF AVAILABLE DATA

The Superstition Hills and Superstition Mountain faults were first mapped, though not named, by Tarbet (1951, scale: 1" = 12 mi.), although the San Jacinto fault zone had been projected into this region earlier (see, for example, Jenkins, 1938). Dibblee (1954) mapped (at 1" = 6 mi.) the Superstition Hills and Superstition Mountain faults as strike-slip faults and provided perhaps the first map with these faults named. He also showed, without names, several of the northeasterly-trending faults north of the Superstition Hills fault. The fault locations of Tarbet (1951) and Dibblee (1954) are shown on Figure 2. More detailed information on these faults is presented below.

Superstition Hills Fault and Wienert Fault

The earliest recorded observation of surface rupture on the Superstition Hills fault was by Joseph Ernst in February of 1951 (Dibblee, 1954; Ernst, 1963; Allen and others, 1965). Ernst observed en echelon fractures from 50 to 100 feet long, along 2 miles (3 km) of the fault. Allen and others (1965) suggest that the ground rupture was a result of a M5.6 earthquake in the Superstition Hills on January 23, 1951.

En echelon ground cracks, possibly a result of a M4 earthquake on November 30, 1965, were noted near Imler Road in December 1965, and again in December 1969 fresh cracks were observed in the same general area, but these were not attributed to any specific seismic event (Allen and others, 1972).

The Borrego Mountain earthquake of April 9, 1968, a M6.5 earthquake on the Coyote Creek fault, triggered surface rupture along 23 km (14 mi.) of the Superstition Hills fault (Allen and others, 1968; Allen and others, 1972). The cracks varied from narrow, well-defined breaks to zones of en echelon cracks up to 10 m wide. Allen and others (1972) mention a pre-existing fault zone up to 1 2/3 m wide and note that while much of the faulting lay within this zone, cracking occurred as much as 7 m away from the older zone. Where the zone of recent cracking was narrow and well-defined it usually coincided with a similarly narrow and well-defined zone of older faulting. Displacements, measured approximately one month after the earthquake, were as much as 1.8 cm right-lateral, but averaged less than 1 cm. Vertical displacements of 2.5 cm were observed on only three short (75 m) segments. There were no indications of after-creep following the initial displacement. The 1974 Special Studies Zone (CDMG, 1974) was based largely on the 1968 rupture with the fault projected based on Dibblee (1954).

On October 15, 1979 slip was again triggered on the Superstition Hills fault, this time by the M6.5 Imperial Valley earthquake (Fuis, 1982). The surface rupture was only slightly less extensive (by less than 0.5 km) than during the Borrego Mountain earthquake and otherwise coincided with the 1968 rupture location. Right-lateral displacement reached a maximum of 2.2 cm, but was mostly less than half that amount. Vertical displacements of up to 0.4 cm were measured. Fuis (1982) presented the most detailed discussion of the Superstition Hills fault to that date. He noted that the fault dies out into an anticline at its northwest end and appear to die out toward the New River to the southeast. He also commented on the left-stepping, en echelon arrangement of the fault relative to the historically active Coyote Creek and Imperial faults to the northwest and southeast, respectively. Regarding the southeastern end of the Superstition Hills fault, Fuis (1982) said that a southeastern extension of the fault might be supported by epicenter locations (see section of this report on Seismicity).

The Westmorland earthquake (M5.6) of April 26, 1981 triggered slip discontinuously along 15.7 km of the Superstition Hills fault with a maximum right-lateral displacement of 1.4 cm (Sharp and others, 1986). It was determined that the surface rupture during this event did not vary significantly in location from previous recorded rupture events and that any discrepancies in recorded rupture locations were due to difficulties in accurately plotting the data, rather then actual rupture of separate fault-traces. Observed vertical displacements did not exceed 0.1 cm.

Up until November, 1987 all of the recorded rupture events on the Superstition Hills fault appeared to be triggered by earthquakes on other nearby faults. On November 23 at 5:53 p.m. a M6.2 earthquake occurred several kilometers north of the Superstition Hills fault (see Plate 1a). Although fault rupture associated with this event is believed to have occurred primarily on northeasterly-trending faults, some rupture (up to 13.6 cm) may have also occurred at the northwestern end of the Superstition Hills fault (Sharp and others, 1989), but rupture did not extend as far south as Imler Road (Kahle and others, 1988).

At 5:16 a.m. on November 24 a M6.6 earthquake occurred near the northwestern end of the fault and extensive rupture, along 27 km of the Superstition Hills and Wienert faults, was recorded shortly thereafter and over the next two weeks (Kahle and others, 1988; Sharp and others, 1989). Rupture took place largely along those portions which broke previously, but additional rupture occurred which defined a right stepover between what Sharp and others (1989) call the North and South strands (see Plate 1c). The fault traces in this stepover mapped by Sharp and others (1989) are located somewhat differently by Kahle and others (1988) and preference is given on Plate 1c to the latter reference, modified by unpublished mapping on which Kahle and others (1988) was based. In this event, as in all previous documented rupture events, surface displacement did not extend northwest of the main wash which cuts across section 20 (T 13S, R 11E; plate 1a). Displacement on the North and South strands was primarily strike slip, exhibiting a maximum of about 50 cm of right-lateral displacement after one day and a predicted maximum final displacement of about 112 cm (Sharp and others, 1989). Observed vertical displacements (up to 26 cm after almost one year) were usually less than the horizontal.

Rupture also occurred along the previously unbroken (historically) Wienert fault (Sharp and others, 1989) (see Plates 1c & 1d). This fault includes what has also been called the Edgar strand (Budding and Sharp, 1988). The fault steps right from the Superstition Hills fault. Although rupture on the Wienert fault was restricted to the Brawley NW and Seeley quadrangles, Sharp and others (1989) map a late Quaternary fault trace (visible only in aerial photos) extending into the El Centro quadrangle (Plate 1e). The fault had dominantly right-lateral slip north of the New River (about 20 cm in mid-December, 1987) but had only vertical slip (up to about 25 cm in February 1988) south of the New River (Sharp and others, 1989).

After-slip has been significant along the entire length of surface rupture on the Superstition Hills fault (both strands) and the Wienert fault. Sharp and others (1989) include both of these faults within the "Superstition Hills fault zone."

At the southern end of the Superstition Hills fault the mapping of Sharp (Sharp and others, 1989) differs markedly from the trace of Dibblee (1954) which was used to project the fault onto the Brawley and El Centro quadrangles (CDMG, 1974 and 1980, respectively). There has been no historic rupture or published field evidence for the traces of the Superstition Hills fault as shown on these two quadrangles or in the southeastern corner of the Brawley NW quadrangle. Sharp and others (1989) also address the possible southeastern extensions of the fault zone where Babcock (1971) showed photo lineaments (Figure 2). They were only able to field check one of three lineaments and concluded that the feature was probably a recessional shoreline feature of ancient Lake Cahuilla, not a fault trace. The possibility of other southeastern extensions is discussed by Sharp and others (1989) but they point out that there is no surface evidence beyond the faults shown (Plate 1e).

Superstition Mountain Fault

The Superstition Mountain fault was first mapped by Tarbet (1951). Ernst (1963) also mapped this part of the "San Jacinto Fault" in 1951. It was later mapped in more detail and named by Dibblee (1954), who plotted two subparallel traces: a main trace forming the southwestern boundary of Superstition Mountain and continuing through the hills to the southeast, and a second trace slicing across Superstition Mountain. A map by Kovach (1962) shows the fault in essentially the same location as that shown by Tarbet, and presents geophysical data to support the location. This location for the valleyward portion of the fault and Dibblee's mapping in the Superstition Mountains were used by Strand (1962). Babcock (1971) used the fault location as compiled by Strand as a starting point to look for evidence of the faults in infra-red imagery. He located several possible short segments near El Centro (more on line with the known and projected locations of the Superstition Hills fault than the Superstition Mountain fault) as well as one other strand, parallel to the main fault, south of Superstition Mountain (see Figure 2). This latter feature was reportedly supported by aeromagnetic data (Babcock, 1971). The current special-studies zone, on the Plaster City NW, Superstition Mtn. and Brawley NW quadrangles (CDMG, 1974), is based solely on Dibblee's mapping (1954 and written communication, 1973).

Following the 1968 Borrego Mountain earthquake (which triggered slip on the Superstition Hills fault) the Superstition Mountain fault was inspected and no displacement was seen (Allen and others, 1972). Sharp and Clark (1972) commented on the possible connection of the Superstition Mountain fault to the Coyote Creek fault to the northwest, citing "alined mesquite-covered dunes... and low hills of upwarped alluvium" as well as a steep gravity gradient (interpreted by Biehler and others, 1964 to indicate a concealed fault) along the inferred connection. Recent mapping by Rockwell (personal communication, 1989) may also support such a connection.

Recent field mapping at a scale of 1:6,000 by Hudnut and Williams (1987) has provided a more accurate location of the traces of this fault than portrayed by Dibblee at 6 mi.= 1 in. (1954) or 1 mi. = 1 in. (written communication, 1973). The fault, as mapped by Hudnut and Williams (1987; see Plates 1b, c, and f), consists of two main strands which include scarps and numerous right-deflected drainages, and at least two other lesser strands (defined by eroded escarpments). The northwestern strand, through Superstition Mountain, corresponds roughly with the second trace of Dibblee. Their other main strand, through the hills to the southeast, appears to be better located than Dibblee's main fault in the same area. A more eroded strand, at the western end of Superstition Mountain, corresponds to part of Dibblee's main trace. There is no surface evidence for the intervening remainder of Dibblee's main strand, which was replotted as a concealed fault by CDMG (1974; see Plate 2b). Eroded scarps at the western end of the fault mapped by Hudnut and Williams (1987), on the Plaster City NW quadrangle (Plate 1f) partially correspond to that shown on the existing special studies zone map (CDMG, 1974). Along this same fault segment, at the western margin of the Superstition Mtn. quadrangle, Hudnut and Williams (1987) noted offset of presumed Holocene sediments.

At the southeastern end of the Superstition Mountain fault Hudnut and others (1987) have described evidence for possible Holocene displacement. They have measured roughly 2 m vertical separation across the projection of the fault at a Lake Cahuilla shoreline feature which may be only 310 ± 40 years old, or perhaps as old as 600 years. The shoreline is cut, at the projection, by an arroyo and the fault was not seen there although minor faulting was noted nearby. Pat Williams (personal communication, 1989) points out that the offset feature, a berm deposit, has not been directly dated and that later work suggests that the higher berm (to the southwest) may be older than the berm to the northeast of the arroyo. He reports, though, that a wave-cut notch on the higher berm is at approximately the same elevation as the berm to the northeast, and therefore vertical separation, if present, may be much less than 2 m. The work of Hudnut and others (1987) is also described in Seeber (1987) where details of some of the offset drainages are also analyzed. Seeber (1987) inferred that the stream offsets may record two separate slip events, the latest on the order of one meter right-lateral, corresponding temporally with the offset of the Lake Cahuilla shoreline deposit. As noted earlier, however, the shoreline offset is equivocal. Also, the right-slip data at this end of the fault is weak (see discussion under Interpretation of Aerial Photographs and Field Observations).

Although there has been no documented historic surface rupture on the Superstition Mountain fault, cracking and possible right-lateral offsets immediately following the November, 1987 Superstition Hills earthquakes were reported (R. Corbaley, 1988, personal communication). Some of his observation are noted on Plate 1b, including his report along the northwestern strand of about 2.5 cm right lateral offset of a fresh tire track across a crack which extends through the "Rock House". Off-road vehicle traffic quickly obliterated such features in this area. Not located are several areas to the southeast where he reported (but did not map) minor but consistent right-lateral offset of gully walls along cracks within a 10 to 12 foot wide zone.

Northeasterly-Trending and Related Faults

The presence of northeasterly-trending faults was first indicated by Dibblee (1954; see figure 2 herein). Many additional faults have been mapped by R.V. Sharp (Sharp and others, 1989), but until 1987 there had been no surface displacement observed on these faults. There are currently no Special Studies Zones established for these faults.

On November 23, 1987 a M6.2 earthquake occurred within a group of northeasterly-trending faults. On the following day, after a M6.6 earthquake near the northern end of the Superstition Hills fault, left-lateral displacement was observed on many of these faults (Plate 1a). It is believed that the northeasterly-trending ruptures resulted from the November 23 M6.2 earthquake (Hudnut and others, 1989; Sharp and others, 1989). Over the next several weeks the surface ruptures were mapped by Kahle and others, 1988 (primarily the Elmore Ranch fault); Hudnut and others, 1989; and Sharp and others, 1989. These three references are generally in agreement with respect to fault rupture locations and local differences are mostly due to different observed or recorded displacements and the difficulty in plotting the data accurately on the available map base. For data compilation purposes (Plate 1a), where different workers show faulting in only slightly different locations or con- figurations a judgement was made to portray only one interpretation. The data of Sharp and others (1989) was generally given preference in most such instances except where the locations of Hudnut and others (1989) had been surveyed with a total-station instrument or appeared to be more complete. Where locations were sufficiently different to clearly portray both interpretations, both were shown on the assumption that they may represent separate ruptures. Three such discrepancies probably are mislocated and are shown with queries added. Additional minor surface rupture (3.2 cm or less) and other late Quaternary faults with no historic displacement were mapped on the Calipatria SW and the Harpers Well quadrangles (Sharp and others, 1989) but are not evaluated in this FER.

The northeasterly trending ruptures occurred primarily in four main zones: the Kane Spring fault, the Elmore Ranch fault (including the West Elmore Ranch fault), the East Elmore Ranch fault and the Lone Tree fault. These main zones, as well as numerous other shorter ruptures, largely followed late Quaternary faults previously mapped by Sharp (Sharp and others, 1989).

The longest surface rupture (nearly 10km) as well as the maximum displacement (12.5 cm left-lateral, 4.5 cm vertical) occurred on the Elmore Ranch fault (previously called Elmore Desert Ranch fault by Kahle and others, 1988). Unlike the ruptures on the Superstition Hills fault there has been no evidence of afterslip on the northeasterly-trending faults (Hudnut and others, 1989; Sharp and others, 1989). Many other faults mapped by Sharp (Sharp and others, 1989) did not show surface rupture (shown as dotted lines on Plate 1a). Right-lateral and vertical displacements occurred along several faults which curve southeastward from the orientation of the northeasterly trending faults asthey approach the Superstition Hills fault. Right-lateral displacement also occurred on several short faults which trend north-northwesterly from the northeast end of the Lone Tree fault.

SEISMICITY

The earthquake of November 23, 1987 can almost certainly be correlated with ground-rupture on the northeasterly-trending faults and the earthquake of November 24 can likewise be correlated with rupture on the Superstition Hills fault. There can be no doubt about the activity of these faults in light of the recent surface rupture. Figure 3 shows additional epicenters spatially associated with the Superstition Hills fault and the general region to the northeast, including a prominent northeast trend of epicenters, not associated with a known surface fault.

Also notable on Figure 3 is a linear trend of epicenters along the Superstition Mountain fault, on the projection of the active Coyote Creek fault of the San Jacinto fault zone. This same epicentral trend continues more weakly to the southeast, through El Centro, toward the Imperial fault. A M6.5 earthquake in 1942 was probably on the Superstition Mountain fault (Bent and Helmberger, 1989).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Superstition Hills Fault and Wienert Fault

These faults were carefully mapped in the field by previous workers on recent aerial photography (GS-SHF) at a scale of 1:8,000 taken following the November 1987 earthquakes (Kahle and others, 1988; Sharp and others, 1989). In light of this detailed work no additional field reconnaissance was attempted. Analysis of the GS-SHF 1:8,000 photos failed to find evidence of the northwesternmost 500 m of the Superstition Hills fault as shown on the 1974 Special Studies Zone map (Plate 2a). A stereo zoom-transfer scope was used with the GS-SHF photos to recheck and modify plotted locations of several small recent breaks in the step-over between the north and south segments of the Superstition Hills fault. Faulting shown by Ernst (1963; see Plate 1c) could only be corroborated (in the GS-SHF photos) along one short segment which was also mapped by Sharp (Sharp and others, 1989). Other late Quaternary faults in this stepover, shown by Sharp and others (1989), were visible in the photos only locally as fault-line features. A review of 1953 USDA photos (1:24,000) confirmed discontinuous tonal lineaments along the extension of the Wienert fault (Plate 1d and e) as mapped by Sharp (Sharp and others, 1989).

Superstition Mountain Fault

Recent (May, 1987) air photos at a scale of 1:6,000 were obtained and studied to corroborate the work of Hudnut and Williams (1987; selected data included on Plates 1b,c, and f). Several of their observations with respect to offset drainages could be confirmed, although field reconnaissance also revealed some inconsistent deflections and in several locations to the southeast it was not clear that deflections were not merely a result of drainage following structure. Sheared bedrock, often with slickensides and striae, was evident in numerous localities along the fault as mapped by Hudnut and Williams (1987), as well as on a few additional lineaments noted during photo review (see Plates 1b and c).

On the Brawley NW quadrangle (Plate 1c) the fault is poorly to weakly defined by surface geomorphology but more clearly delineated by truncation of geologic structure. Indications of Holocene displacement are weak to lacking on the readily eroded slopes in the Borrego Formation. Expansive clay and gypsum growth in the surficial material combine their effects to rapidly subdue small-scale geomorphic features such as might be produced during fault rupture. At the southeastern end of the fault zone, in the vicinity of Huff Road, the fault is not clearly defined in air photos or on the ground. About 1000 feet west of Huff Road the fault zone begins to be intermittently discernible in bedrock and not until about 0.5 miles from Huff Road does the fault begin to have a possible effect on drainage patterns. To the northwest a possible northeast-facing scarp is visible in the Cal Tech photos and further along a small (roughly 15 cm high) southwest-facing scarp, possibly erosionally enhanced, was observed in the field in conjunction with a fault in siltstone and mudstone (section 32, T 14S, R 12E). Roughly 200 m to the northwest a tonal lineament is visible in the Cal Tech 1:6,000 photography where the fault crosses modern alluvium in a wash. A parallel fault splay in section 33 was identified as a lineament in air photos and field reconnaissance verified the presence of a fault in bedrock, but the fault showed no indications of Holocene displacement. Similar zones of older faulting were observed with various orientations elsewhere to the south, as well as to the northwest in the Superstition Mtn. quadrangle.

On the Superstition Mtn. quadrangle (Plate 1b), in section 30 (T 14S, R 12E), the general topography becomes more subdued but the southeastern strand shows better topographic expression (as a low, eroded escarpment) and right-deflected drainages become a little more consistent. Within this stretch of the fault two lines of discontinuous cracks stepping left relative to each other were noted in December 1988. Each irregular line of cracks was on the order of 20 to 30 feet long. Weathering (rounding) of the crack margin was sufficient to suggest that they may have occurred during the November 1987 earthquakes. Although no displacement was discernible the weathering could have obscured displacement of up to a couple millimeters. The cracks could not be relocated during reconnaissance in February 1989, and may have been obliterated by rainfall or off-road vehicle traffic in the interim. To the west, through sections 25 and 24, this strand is well defined by structure and continues to be marked by sheared bedrock and right-deflected drainages as well as local tonal contrasts, probably due to juxtaposed lithologies. This southeastern strand becomes less well defined in section 23, being marked by weak tonal and vegetational lineaments and an eroded back-facing escarpment. A very eroded scarp trending southeasterly from the fault within section 25 may be along an older fault strand or may be an old shoreline feature. Faulting was not observed during a brief field reconnaissance of this feature.

In the general area of section 24 (T 14S, R 11E) the more active portion of the Superstition Mountain fault appears to step right to the northwestern strand. This part of the strand is not clearly defined, and northwest to section 15, appears to parallel, but lie upslope (within bedrock) of a low eroded mountain front. It was not evaluated in the field, and the front appears in aerial photography as an older fault-line feature. At a southwest-facing scarp north of the "Rock House" the ground is noticeably more dissected below the toe of the scarp than above; this suggests that the scarp has resulted from more rapid erosion of weaker bedrock across a contact rather than from displacement. The hillside valley to the northwest also looks more like a product of differential erosion as the relative relief varies greatly along the feature. Much of this area to the northwest is obscured by active sand dunes and dunes of presumed late Holocene age.

The northwestern stretch of this fault strand appears, both on aerial photographs and on the map, to slice across and offset right-laterally Superstition Mountain. Within the intermontane valley in section 9 the fault is well-defined where it displaces late Quaternary alluvial fans and is concealed only by active sand dunes. A fault-scarp angle of about 50 to 60 degrees (measured from ground-level photographs) suggests that the scarp may be Holocene, in spite of the possibility that the scarp, capped with alluvium, has been held up by the underlying granitic bedrock. A history of repeated right-lateral displacement, indicated by offset and beheaded drainages in the alluvial fans, also is supportive of faulting continuing into the Holocene. An arcuate southwest-dipping fault segment in section 9 has a fairly rounded scarp crest but appears in the 1987 Cal Tech photography to have a much more sharply defined base, suggesting either erosional enhancement (unlikely where it crosses a ridge crest) or repeated displacement.

The northwestern terminus of this fault strand along the mountain front and across older (late Pleistocene ?) dissected alluvial fans (sections 5, 8 and 9, T 14S, R 11E) consists of locally well-defined sinuous to arcuate, discontinuous, forward and back-facing scarps. Many of the north-facing scarps, in coarse cobbly alluvial material, have rounded crests but more abrupt toes and scarp angles from 15 to 20 degrees. At one gully crossed by a fault with a 2 m scarp there is in excess of 10 m vertical displacement of the granitic basement, again indicating repeated displacement. The back-facing scarps were generally more dissected, erosionally enhanced and (along with the scarps and features further south in the mountain front) may represent faulting older than the other features which cut the fan surface. Numerous parallel linear drainages in the granitic mountain terrain are probably controlled by jointing, older faulting or differential erosion along diorite (?) dikes which are common in this area. A northward-facing scarp at the western edge of section 5 was mapped by Hudnut and Williams (1967) as a 1 to 2 m fault scarp, but this feature also bears characteristics of a shoreline. A diorite dike observed at the western end of the feature may have provided control for shoreline erosion and, at least at the western end, faulting was not evident in granitic basement which is moderately-well exposed in a linear gully which crosses the scarp. In fact, a fault along the linear gully may be responsible for an apparent westward elevation drop of the fault?/shoreline? feature.

Faulting at the western edge of the Superstition Mtn. quadrangle continues onto the Plaster City NW quadrangle (Plate 1f) and represents either a left step from the faulting previously discussed or a continuation of a partially concealed fault along the southwestern margin of the mountain, as shown by Dibblee (1954). There is no evidence in either the 1953 USDA photos or the 1987 Cal Tech photos of surface faulting along the southwest side of the mountain from section 7 to section 22 (T 14S, R11E; Plate 1b). This area, however is blanketed with Holocene to modern dune sand and late Quaternary (possibly Holocene) lacustrine and fan deposits. Surface evidence of faulting at the northwestern end of this trend is limited to the Plaster City NW quadrangle where two parallel trends of aligned notches, deflected drainages and a shutter ridge lie within the currently established Special Studies Zone (CDMG, 1974). Along the projection of these features onto the Superstition Mtn. quadrangle Hudnut and Williams (1987, and personal communication 1989) found faulted sediments of presumed Holocene age exposed in the east wall of an arroyo. I was able to find what is probably the same fault in the west wall of the arroyo, although our plotted locations vary by several hundred feet. The faulted sediments I observed are nearly flat-lying massive to crudely bedded, fine to coarse-grained silts and pebbly sands which lie unconformably on tilted Borrego (?) Formation which is, in turn, nonconformably on granitic basement. The fault does not extend upward to the modern surface.

The fault trace of Babcock (1971) shown parallel to and southwest of the main trace of the Superstition Mountain fault (Figure 2) is not visible on the 1953 USDA photos and was not further evaluated.

Northeasterly-Trending and Related Faults

The northeasterly-trending faults, including the Kane Spring, East Kane Spring, Elmore Ranch (east, west and main strands) and Lone Tree faults, were carefully mapped following the November 1987 earthquake on the 1:12,000 photos of the GS-SHF photo set (Kahle and others, 1988; Hudnut and others, 1989; Sharp and others, 1989) and no additional field work was considered necessary.

Limited photo interpretation was done for this FER to resolve some possibly mislocated faults in sections 16, 21 and 22 (T 13S, R 11E) where the trace of the East Elmore Ranch fault and several unnamed splays bend southeasterly; in three instances the traces portrayed by Hudnut and others (1989) parallel similar traces of Sharp and others (1989) but at distances of 200 to 600 feet away. These three traces appear to be mislocated as bedding clearly crosses them in the SG-SHF 1:12,000 photos and they are shown on Plate 1a with queries added.

CONCLUSIONS AND DISCUSSION

Superstition Hills and Wienert Fault

The Superstition Hills fault is a clearly active right-lateral fault over it's entire mapped length, having had surface rupture several times in recorded history (Dibblee, 1954; Allen and others, 1965; Allen and others 1972; Fuis, 1982; Sharp and others, 1986, Kahle and others, 1988; Sharp and others, 1989). Whereas earlier events were triggered slip of less than 2.5 cm in response to earthquakes not directly associated with the fault, the 24 November 1987 earthquake caused about 0.5 m coseismic displacement, with afterslip expected to increase the total maximum displacement to about 1.0 m. Afterslip was still occurring as of March 1989.

The newly named Wienert fault, although mapped, was not known to be active until the 24 November 1987 earthquake after which rupture was observed along part of it's trace (Sharp and others, 1989). Displacement was predominantly right-lateral (about 20 cm) north of the New River, but was entirely dip slip (about 25 cm) to the south. The remainder of the fault, as shown on Plates 1d and e, is inferred from a photo-lineament (Sharp and others, 1989) in Lake Cahuilla sediments (presumed Holocene).

Historic rupture along the southeastern part of the Superstition Hills fault as well as along the Wienert fault has shown that part of the trace as previously zoned (CDMG, 1974) was probably mislocated. This part of the zoned trace was compiled from a much smaller scale map by Dibblee (1954 and 1973, written communication) and was apparently inferred along it's southeastern extension. To the northwest rupture has occurred repeatedly with little variation except at the stepover from the north to the south strand. The trace shown on the zone maps (CDMG, 1974) was based largely on Allen and others (1972) and is probably not as accurately plotted, nor as completely, as the most recent work by Kahle and others (1988) and Sharp and others (1989). Observations by Ernst (1963) in conjunction with those of Sharp (Sharp and others, 1989) support the location of a probable extension of the north strand, bringing it over to the south strand at the southeastern end of the fault stepover (Plate 1c). However, this extension has not ruptured historically and is mapped only in the Pleistocene Brawley formation. It is not consistently visible in recent large-scale (1:8,000) aerial photography, and is probably not active or much less active than the northwest end of the stepover.

The Special Studies Zone at the northwest terminus of the Superstition Hills fault (in section 20, T 13S, R 11E; Plate 2a) was based on Dibblee (1954 and 1973, written communication), however no historic rupture has extended west of the wash which runs diagonally across this section, nor has the fault been mapped subsequently in the field or on photos beyond this point.

Superstition Mountain Fault

The Superstition Mountain fault is a locally well-located, predominantly right-lateral fault with equivocal evidence for Holocene activity. Some segments of the fault have no clear geomorphic expression, including areas which are obscured by active sand dunes. General features suggestive of Holocene activity are the broadly linear zone of epicenters along the fault (Figure 3) and the location of the fault along the projection of the active Coyote Creek fault. A connection with the Coyote Creek fault has been suggested by other workers (Sharp and Clark, 1972; Rockwell, personal communication, 1989).

The southeastern strand, although well located along most of its length, is not unequivocally a Holocene feature, particularly at its eastern end where geomorphic expression is very weak and the possible offset of a Holocene shoreline is questionable. Data more suggestive of Holocene displacement are the 15 cm scarp and nearby tonal in recent alluvium (western edge of Brawley NW quadrangle), possible to probable right-lateral offset of numerous drainages and the low welt along the fault in some of the lower relief areas (Superstition Mtn. quadrangle). A southeastern trending eroded scarp near the western end of this strand has no visible faulting and may be an old shoreline feature. Dibblee (1954) inferred a westerly extension of the southeastern, strand along the southern side of Superstition Mountain, but there is no surface evidence for this fault.

In spite of the generally subdued fault topography of the southeastern strand, I believe at least some of this strand should be considered Holocene. Underlying this evaluation is a consideration of how reasonable it is to expect fault features to be preserved. To the north, along the Superstition Hills fault, there are few relict geomorphic fault features from previous events. Even stream offsets are inconsistently preserved. Sharp and others (1989) comment on the lack of older fault features, rapid landscape modification, and the possible ambiguity of apparent stream offsets where, in reality, the stream courses may post-date the previous event (of which nearly all evidence is obliterated). The Superstition Mountain fault cuts across similar terrain along its southeastern strand and the features described may be the best that we can expect.

The northwestern strand also shows little or no evidence of Holocene displacement at its eastern end and is locally covered by Holocene windblown sand elsewhere. The reported historic displacement near the "Rock House" (R. Corbaley, personal communication) does not lie on a mapped trace and may represent lurching or shaking cracks adjacent to an arroyo.

The zone of cracking to the northwest was not well located, showed no displacement and may have been shaking cracks or incipient slumping of dune sands. Where this strand is well-located to the northwest, however, it is marked by clear fault scarps with relatively steep faces which suggest Holocene activity. Within the intermontane valley there are multiple right-lateral displacements of streams incised into a Pleistocene fan surface. Scarp morphology is also suggestive of multiple displacements since this fan surface and the dissected fan to the northwest were formed.

The western strand, again, is quite subdued at its eastern end, but continues with better definition and more impressive fault features on the Plaster City NW quadrangle where there are several abrupt right-deflected drainages. Also supporting possible Holocene displacement are undated, faulted sediments on the Superstition Mtn. quadrangle which were presumed to be Holocene by Hudnut and Williams (1987). There is no surface evidence for Dibblee's (1954) inferred connection of this fault with the southeastern strand.

Northeasterly-Trending and Related Faults

The northeasterly-trending faults which ruptured in 1987 coincided largely with some of the numerous late Quaternary faults mapped in this area and to the north by Sharp (Sharp and others, 1989). Most of these faults have little geomorphic expression but are visible in aerial photos as structural truncations of the Brawley Formation (Pleistocene age) and other lineaments. The distribution of surface rupture in 1987 is the only indication we have at present as to which of these faults are still active. Rupture (up to 12.5 cm left-lateral) was concentrated along four main zones, clearly indicating their Holocene activity. Late Quaternary faults which fill gaps in these zones or extend them are also considered to be active. Additional surface rupture occurred on many smaller faults (Plate 1a). Many of these faults merely showed minor extension while others had displacements of several centimeters. Where several localities of rupture occurred along a previously mapped fault it was taken as an indication that the entire fault is probably active. Shorter isolated segments with displacements on the order of 2 cm or more are also considered probably active, as are short faults with less displacement which appear related to the longer faults. Other faults not ruptured in 1987 as well as small isolated 1987 rupture localities are probably not sufficiently active to warrant zoning.

RECOMMENDATIONS

Superstition Hills and Wienert Fault

It is recommended that the existing Special Studies Zone be modified and a new zone be added as indicated on Plates 2a,b,c,d and e. Roughly 850 feet of the existing zone should be deleted at the western end of the fault since no active fault has been documented in this area. Based on repeated rupture of the same well-defined trace (relocated) the zone should be narrowed to a minimum of 400 feet on either side of the fault, except where faulting is complicated by splays or subsidiary traces. The existing zone should be revised to include recent rupture in the stepover between the north and south strands. A new zone should be established to include the Wienert fault as well as the stepover from the south strand of the Superstition Hills fault. Southeast of the stepover to the Wienert fault there is no indication of Holocene faulting and this portion of the existing zone for the Superstition Hills fault should be deleted. In general, the fault trace based on Dibblee (1954) is inaccurately located and should be disregarded in favor of more recent work.

Superstition Mountain Fault

It is recommended that the existing Special Studies Zone be modified as indicated on Plates 2b and 2c. The existing zone is mislocated by as much as 650 feet, includes fault traces with no surface expression, and should be largely deleted or relocated. Roughly the southeastern 4 miles of the existing zone should be deleted since evidence for surface faulting is entirely lacking at the southeastern end and where the fault is mappable evidence for Holocene displacement is lacking or equivocal. The remainder of this trace, where located at the surface, should be retained in a relocated zone based on stronger, although not conclusive, indications of Holocene displacement. Northwest of the dirt road near the "Rock House" there is little or no surface indication of the extension of this fault as shown by Dibblee (1954) and this portion of the zone, except for the westernmost end, should be deleted. At its western end the fault includes some relatively good indications of Holocene displacement and no changes are recommended for the existing zone on the Plaster City NW quadrangle. The mappable trace projects onto the Superstition Mountain quadrangle (Plates 1b and 2b) where a short revised zone should be retained to include a locality of faulted presumed Holocene sediments.

The northwestern strand of the Superstition Mountain fault (Plate 1b) at its southeastern end is only intermittently located and displays little or no clear evidence of Holocene displacement. From section 15 northwest to section 5 (T 14S, R 11E), although still somewhat discontinuous, the fault shows much clearer evidence of recency and should be retained in a revised Special Studies Zone as indicated. Another feature, an eroded linear escarpment to the west (on the Plaster City NW quadrangle, Plate 1f), is not strongly suggestive of Holocene displacement and is not recommended for zoning. Other faults on this quadrangle were not evaluated. If this quadrangle is revised in the future the zone should be narrowed to correspond with the revised zone to the east, and perhaps modified by future studies anticipated in this area.

Northeasterly - Trending and Related Faults

It is recommended that new Special Studies Zones be established along those faults indicated on Plate 2a and 2b. These faults have either been previously mapped and have had recently documented surface rupture along all or part of their length or they have had recent displacement along previously unmapped faults. Not recommended for zoning are several smaller 1987 surface breaks which had generally less than 1.5 cm displacement and were not connected with any of the more persistent faults. Also not recommended for zoning are numerous mapped late Quaternary faults which have had no historic rupture.

Late Quaternary faults and minor surface rupture on the adjacent Calipatria SW and Harpers Well quadrangles were not evaluated, however, if these quadrangles are evaluated in the future these faults should be considered further.

Reviewed & approved Earl W. Hart 5/8/89

Report prepared by,

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AERIAL PHOTOGRAPHY USED

GS-SHF 11/25/87 black and white, vertical
flight line 1 @ 1:8,000
flight line 2-10 @ 1:12,000

USDA black and white, vertical, 1:24,000

4/10/53	ABN 8M	206-210
4/12/53	ABN 9M	76-79
4/12/53	ABN 9M	178-183
4/18/53	ABN 10M	56-60
4/18/53	ABN 10M	125-129
4/18/53	ABN 10M	163-166
4/18/53	ABN 11M	33-35
4/26/53	ABN 11M	122-127

Cal Tech Superstition Mountain, 5/23/87 black and white, vertical, 1:6,000.
frames 2-1 to 2-35
frames 3-1 to 3-18

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